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THE STARS

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THE STARS

CHAPTER I

ORION, THE MAGNIFICENT

THE beauty of a starlight evening appeals to every person at one time or another, whatever be his walk in life. Yet it is difficult to define what it is that creates this special charm, this appeal to our higher nature.

Millions of men and women share the regret of Thomas Carlyle when he said: "Why did not somebody teach me the constellations, and make me at home in the starry heavens which are always overhead, and which I don't half know to this day?"

The stars are seen by us to differ among themselves in glory. We can detect no uniformity in magnitude, no symmetry in their arrangement; their numbers and distances are incredible; their origin a mystery; and we long to know more about them. There may be some who do not feel, so intensely as do we lovers of the stars, the glory of the picture of Orion in his starry frame; just as there are some whose hearts do not respond to the charms of music or the beauty of a garden. This book is written for those who do instinctively love the stars, and who want to know them more intimately, to call them by

their names, to recognize them, and to be able to tell a friend something special about each different star, and the wonderful discoveries that have been made in regard to Sirius or Mizar or Spica or Algol or any other old friend among the orbs of heaven.

* * * * *

The ancients used to picture some well-known figure (often an animal or a mythological hero) to cover a group of stars and to name them as members of that constellation. The superb constellation—Orion, the hunter of mythology—as seen from northern latitudes in the southern part of the sky at midnight in December, can be identified by the following description: Mark upon paper five dots like a St. Andrew's cross, or like the five of diamonds. On this draw a man's figure facing you, with the two top dots for his shoulders, and the two bottom dots for his legs. The middle dot is his waist and belt, and we mark it by three dots in a nearly horizontal line, where three notable stars lie. Add to this a head which, in the heavens, is shown by a few small stars. If, in addition, you hang from the belt a sword scabbard pointing downwards, you have a fairly complete picture of the stars we see in the constellation Orion.

Afterwards, you will be repaid if you take the sketch outside to compare with the actual stars and to make corrections as well as additions. The first correction might be to make the three prominent stars in Orion's belt incline a little downwards to the left, pointing eastward to the brightest star in the

whole sky, and the nearest of all stars visible to the naked eye in British latitudes. This is Sirius, the Dog-

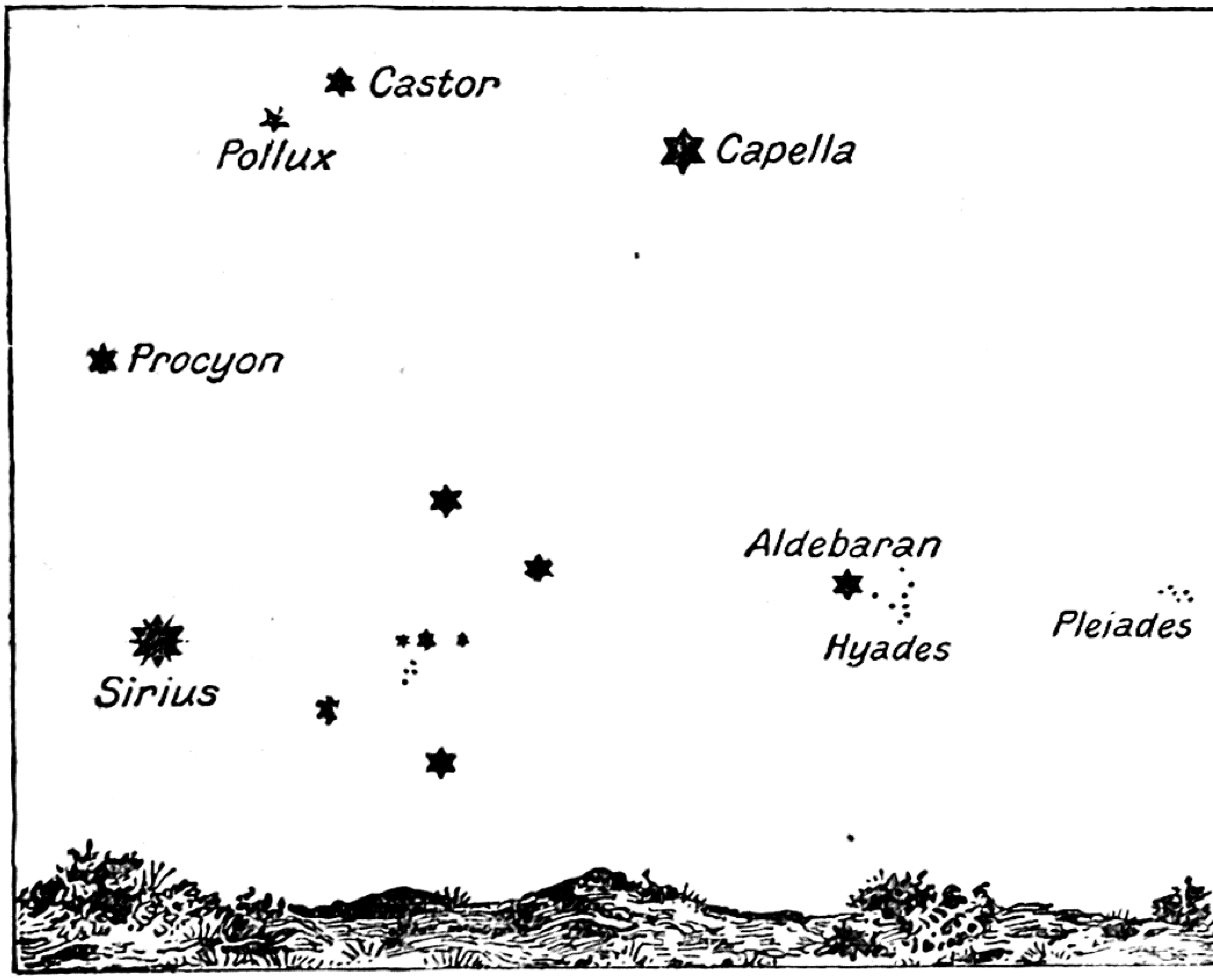

FIG. 1.

The most pleasing orientation for viewing the most glorious picture of stars in any part of the heavens. Orion in centre surrounded by Sirius, Procyon, Pollux and Castor, Capella, Aldebaran, with Hyades and Pleiades to the right; as at 9 p.m. in March.

star. These three stars of the belt are the most notable feature by which we can always recognize Orion. The fact that these equally bright stars, equally spaced

in a straight line, point directly to the great star Sirius confirms us in our recognition of Orion. The peasants in Provence call them "les trois rois," the three kings, who had seen the "star in the east," represented here by Sirius, the lord of all the stars.

Astronomers have drawn a definite boundary line on their star-charts to enclose this picture of Orion as his kingdom. So they have done with all the constellations. In this way the whole heavens have been portioned out into constellations, as our continents are portioned out into countries.

To most persons Orion is known as the grandest of all constellations, partly for its own sake, partly as a rallying point during our visits to all the other stars and constellations, and largely because of the extraordinary brilliance of the starry jewels, which frame it, as it were, in a triumphal arch of stars—Sirius, Procyon, Pollux, Castor, Capella, and Aldebaran. The three stars of Orion's belt point to the two great stars at the base of that arch, to Sirius on the left, and, less exactly, to Aldebaran on the right. And, passing across over Orion's right shoulder as he faces us, is the band of faint white light, which goes by the name of the "Milky Way."

* * * * *

In many ways our antipodean friends have even more magnificent starry pictures than we who live in northern climes. Thus it happens that in New Zealand you can, on looking northwards at midnight in December, see not only Orion, upside down, it is true,

with every member of the triumphal arch of stars that have been named, all of these above the horizon; but also, at the same hour, other brilliant stars of first magnitude never seen in Britain, named Canopus, Achernar, Alpha, and Beta of the Centaur, and the stars of the famous Southern Cross.

A further advantage is possessed by our cousins of the southern hemisphere. In our northern position the part of the Milky Way which we see looks like a broad, faint streak of whitewash over the left upper part of Orion, continued straight on in both directions, beginning and ending at the horizon, always rather faint. Our friends in the southern Dominions, in India, and in many of our Colonies, when looking at the Milky Way, are witness of certain gloriously bright clouds of shining milky star dust of which the southern half of the galaxy is largely built up, an arresting feature there on any moonless night. They also can behold the "rift" in the midst of its radiance, and the black starless "coal-sack." They also have a sight, denied to us, of the greater and the lesser "Magellanic clouds" as they are called, which look like clouds or wisps of the Milky Way detached from their parent, floating alone, clear and distinct to the naked eye.

Even among the brightest stars the New Zealander has advantages over us at home. For he is able to see every one of the twenty-one brightest stars in the sky, though Capella and Deneb, two of our northern stars, are only just above his horizon. Of course, anyone living exactly on the equator, with a clear horizon to

the north and south, can, at one time or another, see every star in the whole heavens.

* * * * *

Returning now to our northern picture of Orion surrounded by its arch of triumphal stars, we may take note that people have given to each bright star in the sky a familiar and a friendly name of its own like *Vega*. But it is also known by the family name of its constellation; with a Greek letter alpha, beta, gamma, delta, etc., or a numeral, for the initial of its Christian name. Let us, then, identify Betelgeuse, on Orion's right shoulder as he faces us, as being otherwise called Alpha of Orion, and the very bright Rigel on his left leg, called also Beta of Orion. In the arch of brilliant stars round Orion we identify, at its left base Sirius, to which Orion's belt points, as Alpha of the "Greater Dog." Above Sirius no one can fail to notice another lone white star. This is Procyon, or Alpha of the "Lesser Dog." Then, following the left side of the arch upwards, you will see a bright pair of golden stars still higher in the sky, Pollux first, then Castor, Beta, and Alpha of the "Twins." And nearly overhead, at midnight in December, is the splendid Capella, Alpha of the "Charioteer." Lastly, at the right base of the arch of stars, is a somewhat ruddy star, Aldebaran, or Alpha of the "Bull." (See Fig. 1, p. 5.)

Already, in a single night, anyone can make the acquaintance, never to be forgotten, of all the stars in Orion, of Sirius in Canis Major, Procyon in Canis

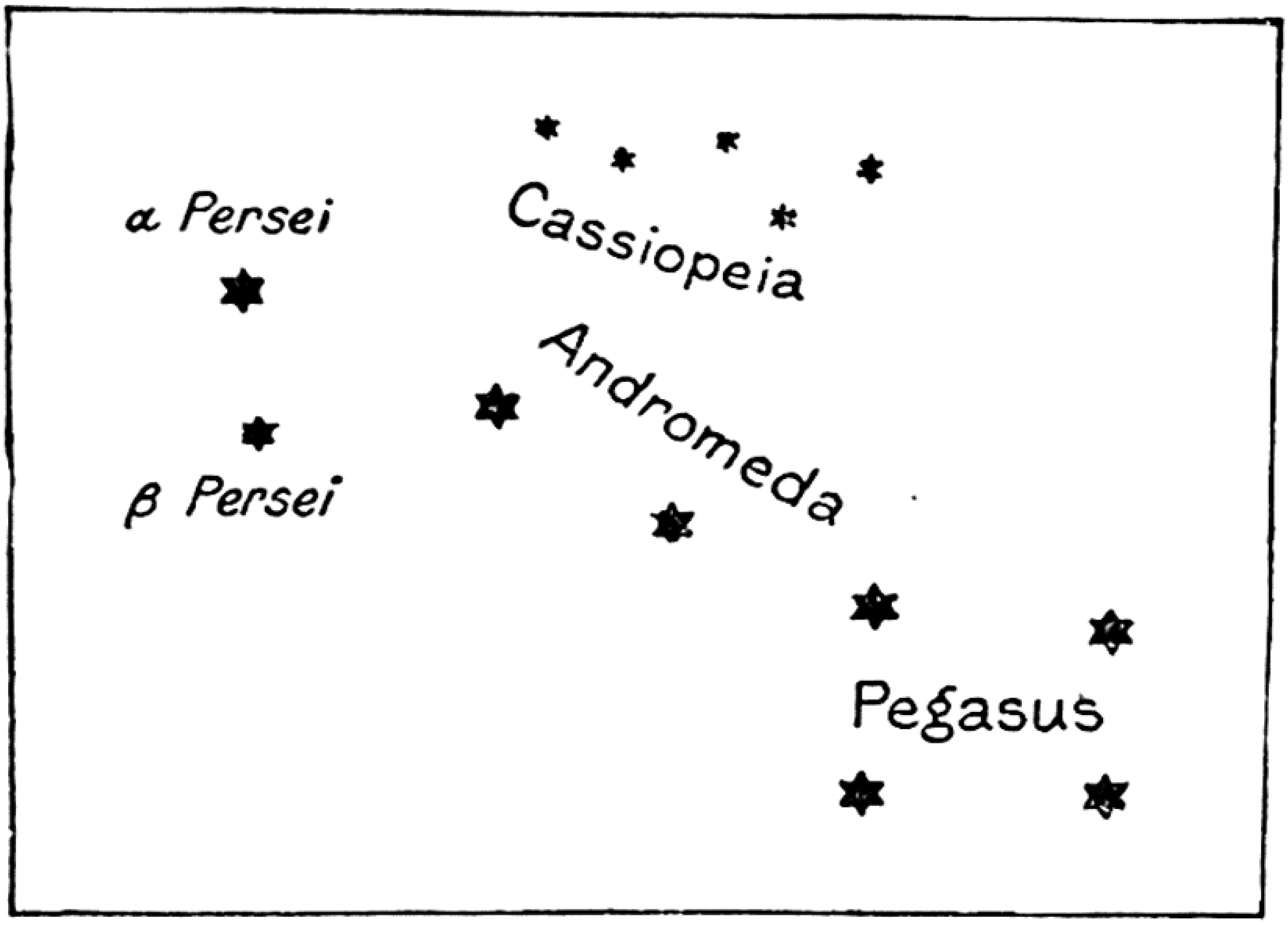

FIG. 2.

The Square of Pegasus, Andromeda, and α Persei. β Persei is Algol, the wonderful variable star. Due south at midnight in September.

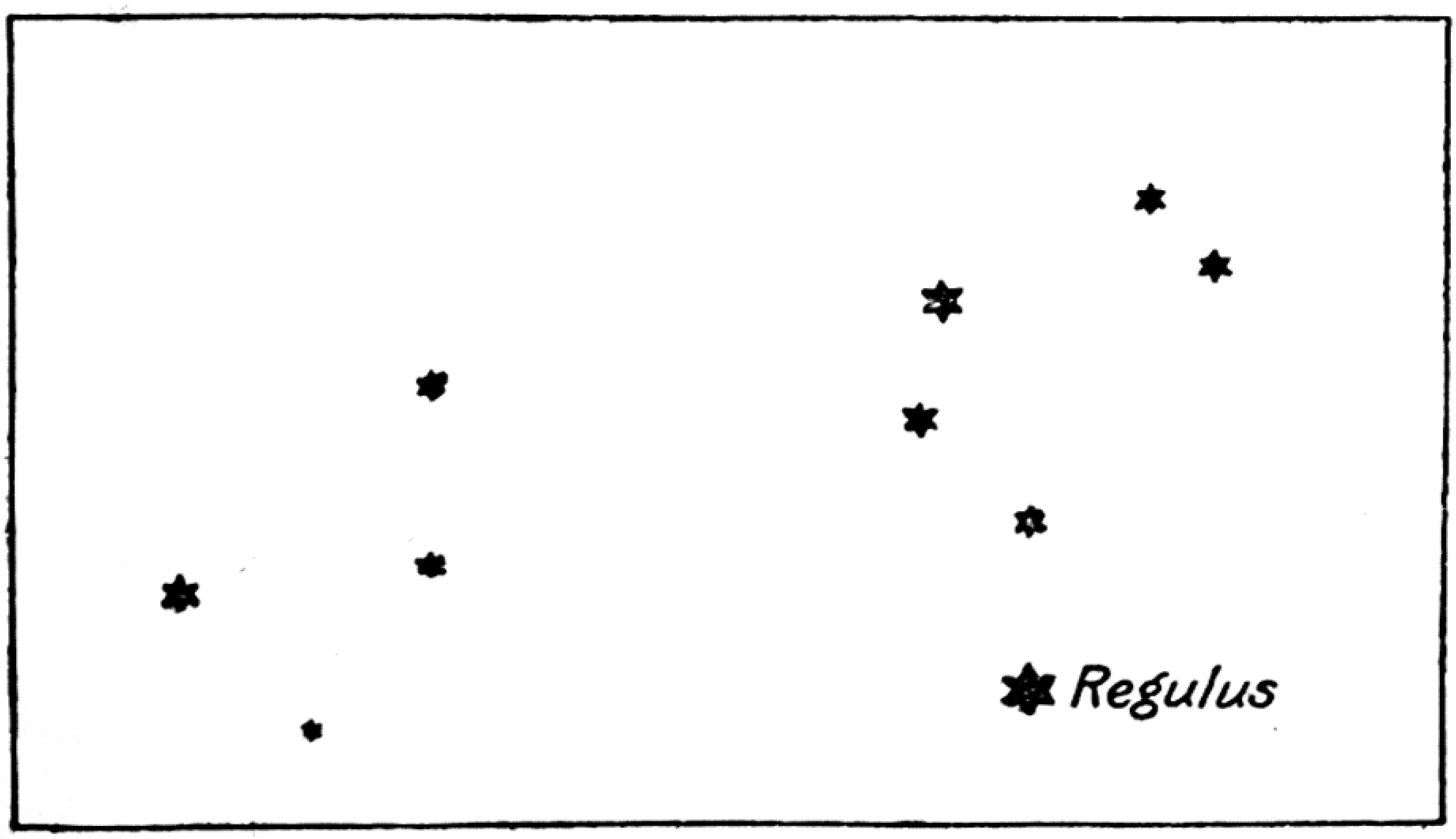

FIG. 3.

The Lion, whose head resembles a reaper's sickle. Due south at midnight in February.

Minor, Castor and Pollux in Gemini, Capella in Auriga, and Aldebaran in Taurus. (The Latin names of constellations are commonly used.)

These six stars form a more complete and sym-

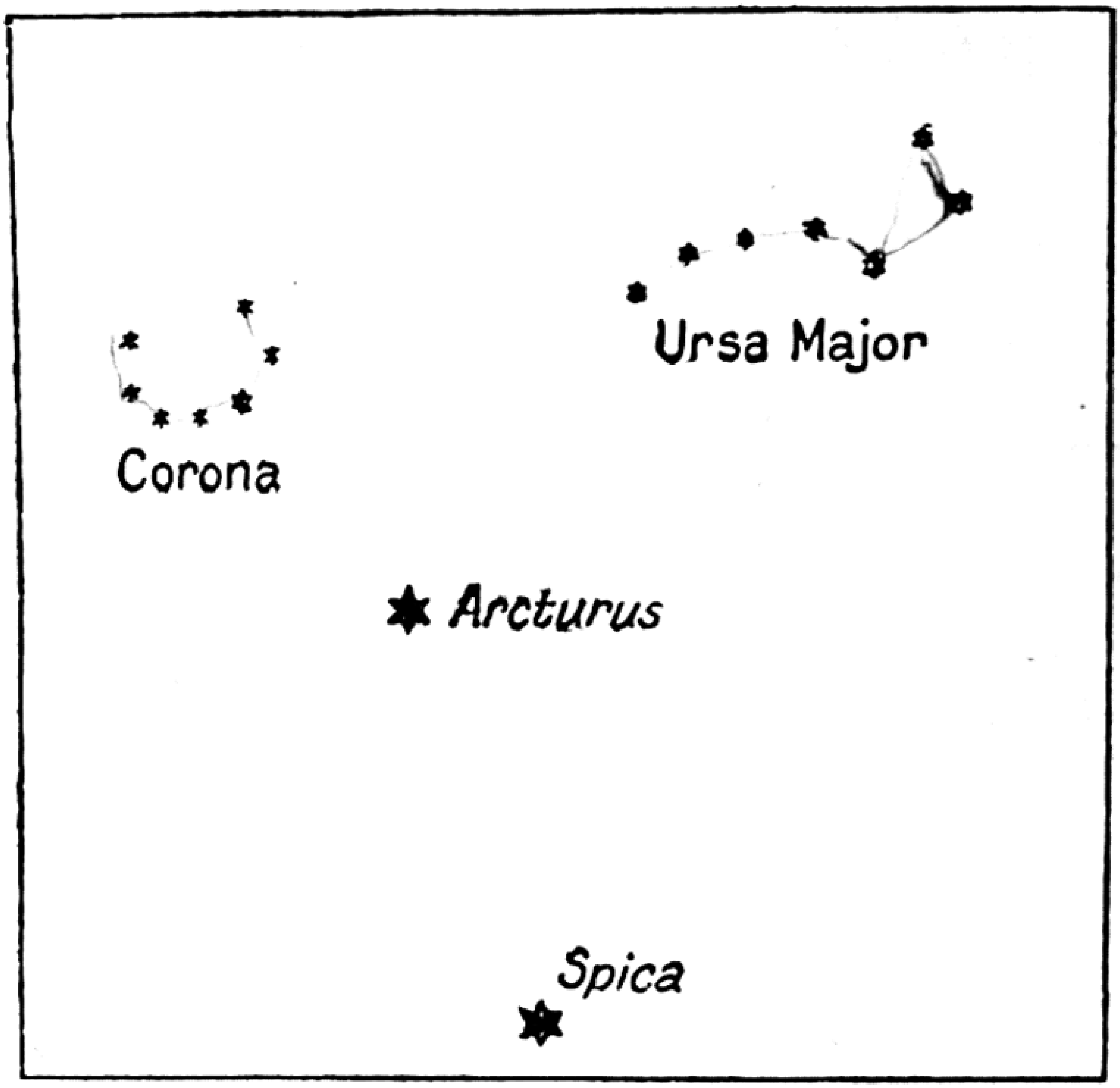

FIG. 4.

The curve of the Bear's Tail if prolonged passes through Arcturus and Spica. Due south at midnight in April.

metrical arch some hours after midnight at Christmastide or, for example, at 9 p.m. in March, as seen in Fig. 1.

It will be found convenient to use Orion as a starting point from which to fix in our minds the order in which other constellations lie. We have to remem-

ber that it lies due south of us at midnight in December; or at 10 p.m. in January; or 8 p.m. in February; always two hours earlier for each later month, because a circuit of the heavens is made in twenty-four hours, or in twelve months. And it rises, or sets, about six hours earlier or later than the hours named here.

Orion is preceded in its rising, and its nocturnal march across the sky, by the Bull with its ruddy bright star *Aldebaran*. It, in its turn, is preceded some four hours earlier by a great square of four stars of the constellation *Pegasus* (Fig. 2).

Orion is *followed* by the *Twins*, by *Sirius*, and *Procyon*, and later by the *Lion* (Fig. 3). The six stars forming the lion's head outline a reaping sickle, with the bright *Regulus* at its handle. And the *Lion* is followed in four hours by the bright star *Spica* near the southern horizon. This is Alpha of the *Virgin*. Above it lies Arcturus, or Alpha of the herdsman, Boötes (Fig. 4). The tail of the Great Bear guides our eye to these.

CHAPTER II

STARS THAT NEVER SET

Stars Round the North Pole

While the picture of Orion is still before us we may do a little practical astronomy. Choose a high wall with its sides pointing north and south. Stand at its north end and, looking southwards along the left, or eastern, side of the wall, you can now, at midnight in December, see that it seems to cut the sky just where Orion is. Perhaps one of the stars in Orion's belt is just appearing to the left of the wall. Watch that star for a quarter of an hour and you will see it disappear behind the wall. In other words, the Orion stars are travelling westward. Of course we all know that really it is the earth that rotates in the opposite way, carrying us with it.

Now go to the south end of the wall and you will see that the stars high up in the sky, like our friend Capella, overhead, travel much more slowly to the west (now at our left), while those low down near the north horizon actually travel in the opposite direction, to the right, which is eastward; and at a certain point pretty high up the motion of the stars is insensible. This marks the pole of the heavens.

If at any hour of the night you hold a straight rod over your head to pass from Orion to Capella, and carry your eye as much further along the same line,

you will then reach a moderately bright star in the north. You have, in fact, discovered the Pole Star, round which the whole vault of heaven, carrying all the fixed stars and planets, and sun and moon, seems to revolve once in about 24 hours. Really it is our earth that completes a rotation in 23 hours 56 minutes by our clocks. This is the interval of time taken by every fixed star, which we have seen to be in line with the north and south wall, before it returns again to hold the same position; four minutes short of a solar day.

Anyone who possesses a camera with rapid lens (short focus, large aperture) would be delighted to see the result of exposing a rapid plate in the direction of the Pole Star. Fix the camera in position and leave it to expose for two hours. The result may be almost unseen in the negative, but a print will show the rotation of the stars round Polaris, the Pole Star. This star is almost motionless; each of the other stars describes a twelfth of a complete circle in the two hours, so the streak shown by each star has a greater length the farther that star is from the Pole Star. The resulting picture is very convincing as to the earth's rotation.

The apparent daily and nightly motion of the whole heavens is really caused by the motion of the earth on which we stand. It rotates on its axis once in 23 hours 56 minutes of solar time, or 24 hours by a clock regulated to go quicker, for the stars, to give "*sidereal* time." When we have such a sidereal clock, each star is found to cross our line of sight, along the surface

of the north and south wall, always at the same hour of sidereal time, on every night of the year during which that star can be seen at night. In fact, we can thus identify every individual star by the hour (sidereal) when it crosses our wall, and its height above the horizon.

* * * * *

How to find the Pole Star at any time of Night.—You have already discovered certain facts about the rotation of the earth, as shown in the daily motion of the stars. One fact is clear, that stars seen just above the north horizon never set, and many stars, being nearer to the Pole Star than is our northern horizon, can never set. There are also stars in a circular region round the South Pole which we never see.

There are two very notable constellations near the North Pole at nearly equal distances from the Pole Star, in opposite directions from it. One is called the "Great Bear," out of which seven bright stars go by the name of the "Plough" in England, and the "Dipper" in the United States. The other constellation is called "Cassiopeia," or "Cassiopeia's Chair."

These circum-polar stars, being always above the horizon, are *always* available as a guide, so long as we have no clouds, for finding firstly the Pole Star, and then all the other stars. The seven stars of the Plough are so easily recognized, whether seen direct below the pole or upside down above it, or sideways, that it becomes a splendid guide. Four of its stars

form the ploughshare in front, the other three are the handle of the plough behind, and the plough's for-

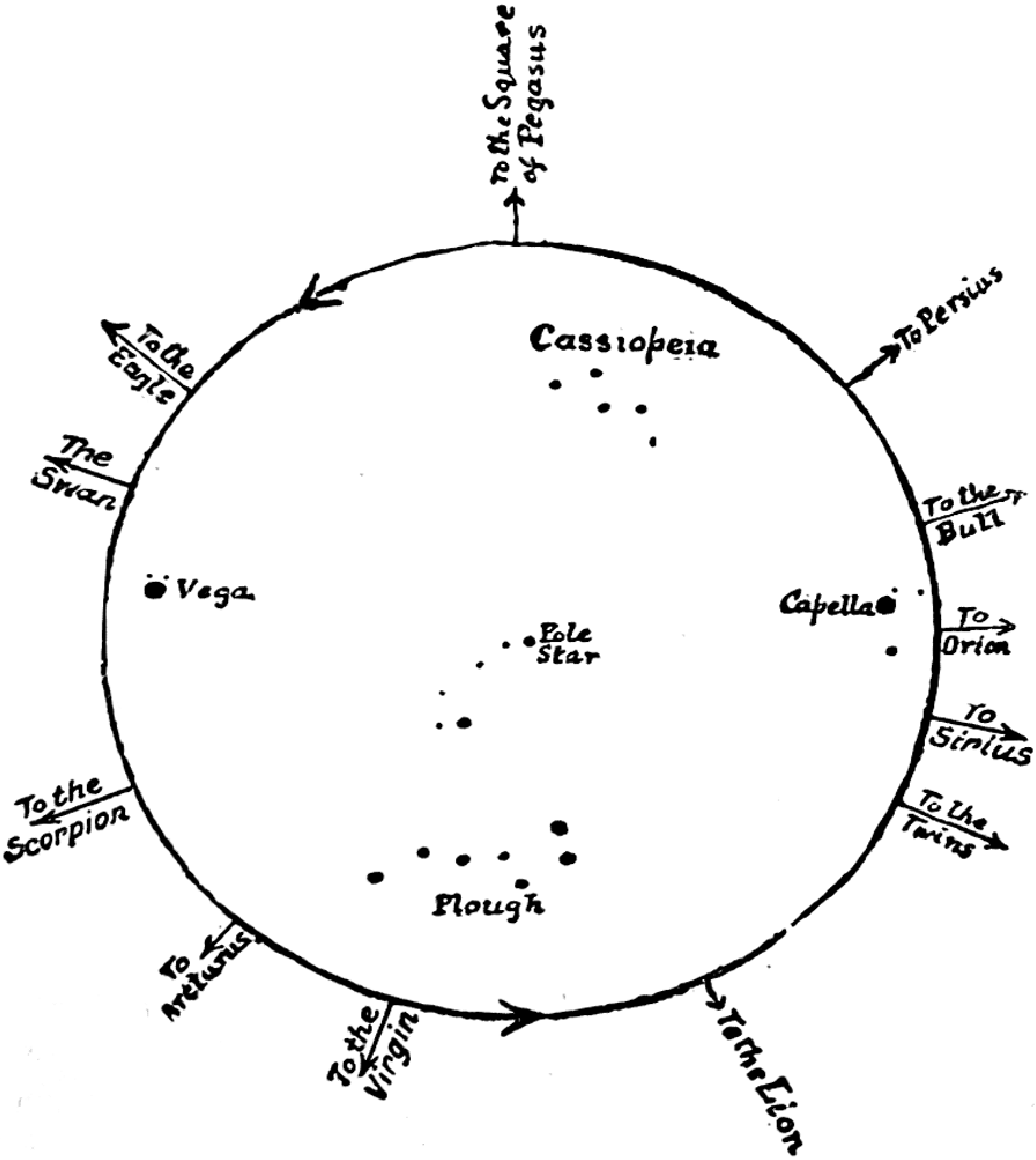

FIG. 5.

Key-map of Circum-polar Stars, rotating nightly round the Pole in the direction shown by arrows.

ward course shows the direction of its nightly revolution, towards the star Capella, already an old friend.

The two front stars of the ploughshare are called "the pointers." They point to the Pole Star, about as far from them as the length of the plough.

Next, continue a line from the middle of the Plough, through the Pole Star, and as far beyond. You then reach the constellation Cassiopeia, or Cassiopeia's Chair, consisting of five stars lying in the shape of a **W**.

The other quarters of a ring drawn round the Pole Star as centre are occupied by Capella in front of the Plough, and Vega, a lovely bluish star, behind the Plough. Vega is accompanied by two small stars forming with itself a regular triangle, very small, but useful for assuring us that this is really Vega, or Alpha of the "Lyre" (see Fig. 5).

* * * * *

Having now discovered and mapped out the circular chart of northern circum-polar stars, we have a guide to all the constellations, and a key to the special stars which appear at any hour of any night in the year.

My own special Boy Scouts used to mark the inside of an umbrella with white bits of paper for the stars in the Plough and Cassiopeia, for Vega and Capella. They would point the top of the umbrella to the Pole Star, and turn it round till Capella was overhead. This gives the position of all of these stars for midnight in December. A quarter of a turn to the left gives the position 6 hours, or 3 months, later, and this brings the Plough, upside down, to the top,

and so we learn that this is the position for 6 a.m. in December, or for midnight in March. Vega is at the top in June at midnight; and Cassiopeia in September. A quarter twist forward or backward represents either the 3 months at a fixed hour or 6 hours at a fixed date. Thus the Boy Scouts were able to give for any hour at any time of the year the correct position of the umbrella to represent truly the positions of the circum-polar stars. They could even tell the time of night, roughly, from the star positions, by their handling of the umbrella.

But they went a step further. They hung a curtain round the rim of the umbrella, and marked the most prominent stars on it by little bits of paper. For example, we already know that Orion would lie upon this curtain, under Capella.

Finally each of them kept a card with a circle containing the circum-polar stars, and arrows to mark the positions of stars and constellations with which they were familiar. This card, as shown in Fig. 5 (p. 15) became a guide to the heavens, as well as a kind of astronomical clock; and some boys did not need the card. They came to know it by heart, and could work out the star positions for any date and any hour in their heads.

* * * * *

A circular chart of the same character can be made for the southern circum-polar stars. Here the guiding constellation is the Southern Cross, a fine group when upright, although we miss a middle star as demanded

by the form of a cross. When voyaging towards the Cape, on reaching the trade-wind latitudes near the Cape Verde Islands, some 20° north of the equator, at midnight in March, or at any other month and hour when the Plough attains its highest point in the north, the traveller sees the Southern Cross standing upright over the southern sea horizon, pointing downwards to the south pole of the heavens, which is 30° below it. Thus did Sir David Gill first see it when on his way to the Isle of Ascension in 1877, in hopes of solving the vexed question of the true distance of the sun. And he has told me how impressed he was at this aspect of the Southern Cross shining in the bright Milky Way close to its black, starless, pear-shaped emptiness called the "coal-sack"; and how he took the upright Cross as an emblem and omen of success to his hopes. And, to the joy of all astronomers, success followed the omen.

To the left, and pointing to the Cross, are two first magnitude stars, Alpha and Beta of the Centaur. These are brilliant guides to the Cross, which itself is always above the horizon in high southern latitudes, and is used very generally by huntsmen and travellers, not only to replace the compass by showing the south point, but also for telling the time by the slope of the cross to the horizon.

The brightest of southern circum-polar stars is Canopus, the greatest of all stars in the heavens except Sirius. These two stars, Sirius and Canopus, are seen to rise and set nearly at the same hour, if we are on the equator.

That half of the southern circum-polar region wherein the Cross lies centrally exhibits a brilliant part of the Milky Way, dotted with many bright stars. The other half that is on the opposite side of the South Pole is singularly devoid of these. Achernar alone, called also Alpha of Eridanus, of the first magnitude, shines brightly in that part of the heavens.

Everyone wants to know the names, at least, of the bright stars, and of the striking groups of stars called constellations. The brightest *fixed stars* are, in order of brightness: (1) Sirius, (2) Canopus, (3) Alpha of the Centaur, all in the southern half of the sky. Then come (4) Vega, (5) Capella, (6) Arcturus, in the northern half. After these we have, in order of brightness, (7) Rigel in Orion, (8) Procyon, (9) Achernar, (10) Beta of the Centaur, (11) Altair in the Eagle, (12) Betelgeuse in Orion, (13) Alpha of the Cross, (14) Aldebaran, (15) Pollux, (16) Spica, (17) Antares, (18) Fomalhaut, (19) Alpha of the Swan, and (20) Regulus.

All of these are often spoken of as first magnitude stars; although the first one, Sirius, is sixteen times brighter than the last one, Regulus.

CHAPTER III

THE WANDERING STARS

The Planets

It often happens that the star which catches our eye is not a fixed star, but is one of the wandering stars, or planets, concerning the appearance of which a few words must now be said. Jupiter, Mars, Venus, and the other planets differ from the fixed stars principally in two respects. They are not fixed, but move about from one constellation of stars to another, along a straight, continuous path, nearly the same for all of them. And again, each of them varies in brightness from month to month, and it is only now and then that any one of them actually compels our attention by its brightness.

It may surprise some of the less careful watchers to know that there are only five of these planets ever visible to the naked eye. All of them are occasionally very bright. They are Mercury, Venus, Mars, Jupiter, and Saturn. And for practical purposes Mercury may be left out of account, because he is small, and, being never more than thirty-three degrees away from the sun is not so often seen in our climate.

The four principal planets, brilliant lamps of the sky, are admired by all, and often we hear the query: "What is that lovely star we see every evening now

in the west?" The answer is very sure to be: "The planet Venus"—a round planet shining, like all the planets, by reflecting the sun's light, and showing in a telescope all the phases of the moon, but in a year and a half instead of one month. It is nearer to the sun than our planet the earth.

Sometimes the query may take this form: "Before going to bed, lately, we have been noticing a wonderful great star in the south. What star is it?" The answer will be: "It must be one of the three planets that are further from the sun than our planet the earth—either Mars, Jupiter, or Saturn." An astronomer might, of course, know which of them is in that direction at that time. But a moment's inspection would suffice to make this known to anyone who cares enough about the stars to notice things for himself.

* * * * *

How to know the Planets.—There are three ways of knowing a planet as such when we see it. The first two are very quick and easy to apply, but not so certain as the third. The first clue is this: Whenever you see an unusually bright star, unless it be Sirius, it is probably a planet in that part of its orbit where it becomes brightest to the inhabitants of our planet the earth. Take Venus, for instance, on a circle that is always inside the earth's orbit. She does not shine by her own light. The half of her next the sun is lighted by the sun; the rest of her is dark to us. So, when Venus is nearest to us, we are looking

at her dark side, which is invisible. When she moves a little away from that position we see a little of the illuminated half like a crescent moon. Venus is never at a greater distance from the sun than about forty-five degrees. When at that place she looks in the telescope like a half-moon. She is then nearly at her brightest. For when she goes farther round, turning to us the whole of the illuminated hemisphere, she is so far away that the light is much feebler.

During the period that Venus is about forty-five degrees from the sun she is brighter for weeks than any other star or planet, and can easily be seen before sunset. In fact, she can then be seen sometimes at midday, if you know where to look; and I have seen her casting a shadow on the deck of a steamer.

None of the other three planets is at its brightest when near the rising or setting sun. For they are then near their greatest distance from us. So, if we see an extremely bright star in the west at sunset, or in the east at sunrise, we are very safe in asserting that it is Venus.

As to the other planets (Mars, Jupiter, Saturn) outside the earth's orbit, they are brightest when nearest to us—that is, when sun, earth, and planet are nearly in line, and in that order, and we see the whole hemisphere of the planet that is illuminated by the sun from the dark side of the earth. That is why a very bright star in the southern sky, long after the sun has set, is probably Mars, Jupiter, or Saturn.

It is generally possible to judge, by mere inspection, which of the three planets we are looking at.

Mars is always red, and becomes fiery red when it is nearest to the earth and at its brightest. Jupiter is much the largest of all the planets, and is invariably a very bright star; but he has not the red colour of Mars, which colour is doubtless due to the sandy soil of Mars. The more distant planet, Saturn, is duller and yellowish.

With a pair of opera glasses Jupiter can always be positively recognized, because he has four moons large enough to be almost visible to the naked eye, besides five very small ones. Some of the four Galilean moons (discovered by Galileo)—often all four—may be seen at any time with a small glass, and, as they are close to Jupiter and all lie on a line going through the planet, they cannot be mistaken, though constantly changing position. If, then, the glass shows three or four small specks of light on a line going through the planet, we may be sure we are looking at Jupiter. These moons changing their positions on the line are a constant delight to anybody with a small telescope.

If you direct upon the planet Saturn a telescope larger than the little one that suffices to show Jupiter's moons, you know at a glance which planet it is. For it is not round, but elongated, owing to the marvellous flat ring that surrounds its equator, generally tilted at an angle.

* * * * *

The second clue for identifying a planet among the stars is most useful when the planet is not at its

brightest—not brighter than some of the fixed stars. *The fixed stars generally twinkle, the planets almost never.* Everyone has noticed on a clear night the rapidly changing brightness of stars, called twinkling or scintillation, often accompanied by sparkling colours like the flash from a diamond. It is caused by small patches of irregular density in the atmosphere which deflect from the eye a ray of light that ought to reach it. The effect is momentary, because the patches are in motion and quite small. It is constantly repeated, because there are many patches. Some stars twinkle more than others.

Everyone knows that our atmosphere bends a ray of light from a star downwards, and that the light of a star contains rays of different colours that are bent to different degrees by the atmosphere. Thus the rays of different colours of which a star's light is composed do not all follow exactly the same paths from a star to our eye. It follows that the atmospheric patches causing scintillation, in their motion, deflect the different colours, not all at once but in succession. If green be deflected from the eye the star looks red, and *vice versa.* This is easily seen in a spectroscope attached to a telescope. But a very pretty experiment may be made without any special apparatus, showing the effect in a beautiful manner.

If a small telescope or an opera glass be pointed to a star, and if we keep on tapping the instrument, then the star seems to move about. Its image persists on the retina for a fraction of a second. So the moving star-image looks like a string of light that can be

twisted into a coil of different shapes by judicious tapping.

Now, if the star be a good twinkler, the string of light seems to have gaps in it, showing when a patch is deflecting the ray of light out of our line of vision. But this is not all. The patch deflects different colours in succession. Sometimes green, sometimes red, is deflected from the eye. The result is that the string or coil of light is converted into a beautiful pearl necklace, interrupted, not by mere dark gaps, but by the brilliant scintillations from diamonds, rubies, sapphires, and emeralds. Try this experiment, and show it to your friends.

These remarks on twinkling help to explain why fixed stars twinkle and planets do not. A star is at such an enormous distance that, in spite of its great size, it looks like a mere point of light. But a planet is near enough to show a disc of sensible size in a telescope. A patch in the atmosphere may deflect from our line of sight a ray of light coming from a point like a star, and yet be too small to affect all the rays coming from different parts of the planet's surface. This is the reason why you may be sure that a star which twinkles is not a planet.

The two clues already given for distinguishing planets from other stars are not absolute. The third clue is the only sure and certain test. It depends upon the position of the doubtful object among the other stars. After we have got to know some of the constellations, and noted the places occupied by planets, we make this great discovery: that planets do not

turn up in all parts of the heavens. In the greater number of the constellations planets are never seen. There is, in fact, only one straight road or track among the stars, and not a very broad one, in which we ever see a planet, or the moon or the sun. At first it seems almost absurd to speak of the sun following a track among the stars, as we do not see the stars in daytime. But this happens only because the sun's light illuminates the atmosphere and makes it brighter than the stars. It is a surprising truth that the stars are shining just as brightly by day as by night. The sun and the moon, being both wanderers among the stars, were in old days included among the planets.

How can we trace the path among the stars which is followed by the sun, the moon, and the planets? Sometimes we have the good fortune to see three planets at the same time. In that case we can see for ourselves that the path is a straight line right round the earth. It is not easy to imagine correctly a straight line among the stars. The best plan is to hold up a walking-stick, and we find that it covers all three planets at the same time, provided no two are very close together. This is true all through the year, so the track is continuous right round the earth. Thus we learn from our own observation that the planetary orbits all lie nearly in one plane through the sun.

While holding the stick in line with any two planets it is easy to note those stars and constellations that are covered by the stick, and to continue the line among the stars that form the apparent path of the sun, the moon, and the planets. This path is called

the ecliptic: a word strictly used for the path of the sun among the stars, but applicable also as a nearly perfect guide to the paths of the planets and the moon.

In this way we might be fortunate enough to see the moon halfway between Aldebaran and the Pleiades, while Mars might be in the Twins, a little farther from the Pole Star than the bright stars Castor and Pollux. If Saturn happened at the same time to be near the bright star Regulus in the Lion, and Jupiter at Spica in the Virgin, we should be able very easily to trace out with our stick the whole of the northern half of the ecliptic, which, to us, in these latitudes, is its most interesting part. The only other really bright star on the ecliptic is Antares, in the Scorpion, more favourably situated for people in Southern latitudes.

With the help of a star atlas, or some *Easy Guide* containing pictures of the constellations, it is a very simple affair to get to know the constellations lying upon the ecliptic, the twelve signs of the zodiac, which divide the yearly path of the sun into twelve months. This occupation goes far towards completing our familiarity with any stars that happen to be shining, at any time of the year.

After this has been done no one can be in doubt about a planet. If a star we are looking at is not on the ecliptic it cannot be a planet, and, knowing all the bright stars on the ecliptic, we cannot mistake them for planets. The names of these constellations of the ecliptic, called signs of the zodiac, if remem-

bered in their proper order, are a great help towards recognizing other stars.

They are:

Aries *Taurus* *Gemini*
The Ram, the Bull, the Heavenly Twins,
Cancer *Leo*
And next the Crab, and Lion shines
Virgo *Libra*
The Virgin and the Scales,
Scorpio *Sagittarius* *Capricornus*
The Scorpion, Archer, and He-goat,
Aquarius
The Man who bears the Watering-Pot,
Pisces
The Fish with glittering tails.

Only some of these constellations are conspicuous. The Bull will be recognized by its bright star Aldebaran and the little cluster of stars called the Pleiades; the Twins by Castor and Pollux; Leo by its sickle-like shape and the bright star Regulus; the Virgin by Spica; and the Scorpion, rather near to our southern horizon, may be recognized in summer by the bright red star Antares.

Using some small star atlas with an electric torch, anyone can see nearly all of these in the course of a single night; the ecliptic constellations following one another in the order given above.

CHAPTER IV

THE ARCHITECTURE OF THE FIRMAMENT

OUR imagination is apt to run riot when we begin to speculate about the universe of stars which forms our stellar system, with our solar system somewhere in the middle of it. We want to know more about the number of the stars, their incredible distance from us, and the purpose they serve in those far away regions of space. Do the starry regions extend to infinity? Or has the universe of stars some definite boundary? And if it has, what is the shape of the boundary? As to the different regions of space that are occupied by stars, are they all filled with stars to the same extent? Or are some regions more crowded, others more empty? Can we discover the size, weight, temperature, etc., of different stars? And in these respects are there different kinds of stars in different parts of space, like the human differences on our four continents—white, yellow, red, and black men? Or is there the same kind of star in every region of space? Do they undergo changes in size, brightness, etc., in the course of ages? Whence do the stars derive the energy that maintains them as hot shining things? Are they absolutely fixed in position? If not, do they move singly or in battalions? Does gravitation, universal in the solar system, extend to the stellar distances?

Suchlike questions have always intrigued, and will always intrigue, those astronomers who are blessed with a powerful imagination or insight into the unseen. No astronomer who is loyal to astronomy, the queen of the sciences, our glorious science of absolute truth, ever claims for his pure speculations more than this—that, at best, they can be no more than an expression of the most probable guesses or opinions concerning the limited number of facts that constitute our small amount of knowledge, or great amount of ignorance, at the present time. And such an astronomer never forgets that the present time is a very early century of the world's progress in discovery.

Bearing this in mind, it is permissible to derive the highest possible intellectual enjoyment, not only from the established truths of our science, but also from the ingenuity of pure speculations which have led to some of the most fascinating, all-embracing guesses or hypotheses. These are to-day being supported in the hope that, under test, some of them may have more than an ephemeral place in the history of astronomy. The amount of progress in this direction during the present century has been enough to extend our outlook upon the stars from a mere state of wonder and curiosity almost to a personal friendship, and certainly to an overwhelming interest and joy in the marvels to which each star in its own way does bear witness. It often does this in a language free from any ambiguity, whose dictionary we are still engaged upon compiling, by observation of the stars, and by experiments in the laboratory.

It may seem almost incredible to many that the number of stars we see at any one time never exceeds some two thousand; but this is true. Of course, we have only half of the stars above the horizon at once, and, near the horizon, faint stars are generally dimmed by haze. And further, the middle part of the retina of our eyes is less sensitive to the light from a star than other parts; and it is only the picture of external objects upon the retina that we see, and not the objects themselves. Hence, in a casual glance at the stars, we see a great number indirectly, which disappear when we look straight at them to make sure before counting them.

This is the reason why, without clearly seeing them, we do get a glimpse of many more stars than the two thousand or so that we can count with the naked eye.

In the year 1610, Galileo first pointed his little telescope to the white streak across the sky which we call the Milky Way. He discovered in a moment the surprising truth that its light comes from innumerable minute stars, too feeble to be seen individually without a telescope.

* * * * *

STAR MAGNITUDES.—The brightest stars, some twenty of them, are spoken of as *first magnitude* stars, though they differ in brightness. The Greeks used the name, and divided the visible stars according to magnitudes. They called the faintest visible stars sixth "magnitude," those of intermediate brightness being magnitudes 2, 3, 4, and 5.

This nomenclature is unfortunate, as the star of greater "magnitude" is the fainter. To give the system greater precision, we now say that each magnitude is $2\frac{1}{2}$ times brighter than the next, or that the brightness is 100 times greater for a difference of 5 magnitudes (noting that $2\frac{1}{2}$ multiplied by itself 5 times is almost exactly 100). Thus we say that a star of magnitude 1 is 100 times brighter than the faintest we can see, of magnitude 6.

The smallest star that can be detected with a very large telescope is about magnitude 21, or 20 magnitudes difference from a star of magnitude 1. If $2\frac{1}{2}$ be multiplied by itself 20 times, we get nearly 100,000,000. So a first magnitude star is a hundred million times brighter than the faintest star to be seen in that powerful telescope.

Aldebaran in the Bull is almost exactly of first magnitude. Our old friend Vega is $2\frac{1}{2}$ times brighter, a difference of 1 magnitude, and is very properly described as being of zero magnitude. Sirius, the monarch of fixed stars, is so bright as to have the *negative* magnitude $-1 \cdot 6$. The sun's brightness is given by the negative magnitude -26; ten thousand million (10,000,000,000) times brighter than Aldebaran as seen by us.

* * * * *

THE NUMBER OF STARS.—The number of bright stars is far less than the number of fainter ones. There are only 2 stars brighter than magnitude 0; 11 brighter than first magnitude; 39 for second; 133 for third,

446 for fourth, 1,466 for fifth; and 4,732 for sixth magnitude.

Passing on to those seen with a telescope, the estimated numbers increase to gigantic numbers: 139,300 for the ninth magnitude; 2,588,000 for the twelfth; 27,540,000 for the fifteenth; and the estimated number of stars brighter than the twentieth magnitude is 530,900,000.

With the largest telescope in the world to-day, the 100-inch diameter reflecting telescope at Mount Wilson, U.S.A., there are probably over a thousand million stars that could be detected on a photographic plate.

Astronomers at Greenwich Observatory have estimated, on fairly good grounds, that the total number of stars in space belonging to our stellar system is limited to three or four thousand million. An American estimate is thirty thousand million stars. The investigations on which these estimates are made indicate that beyond some unknown but definite distance there comes a limit beyond which there are no more stars belonging to our star system. And further, that this limiting distance is far greater in directions towards any part of the Milky Way than towards other parts of the heavens.

Astronomers of to-day, however, are inclined to believe that far beyond these limits there are many other isolated star systems like our own. These are the telescopic *cloud-spots* among the stars called "white nebulæ," such as the Great Nebula of Andromeda. And it is suggested that if there be inhabitants of planets in that system, they would see *our* stellar

universe in a powerful telescope like one of these cloud-spots as seen by us.

It is a startling conclusion, at this date commonly accepted, that our own universe of stars is strictly limited in extent, and also in the number of stars contained in it; and that it is even possible to get a close estimate of the shape of the boundary within which our star system is enclosed.

* * * * *

Distribution of the Stars.—Is there any concentration of stars in the different directions of the heavens? Let us consider the bright and faint stars separately. The nearer a star is to us, the brighter it will shine. The stars we see without a telescope are the brightest stars and, on the whole, probably the nearest. None of us, however, would say that we notice any overwhelming concentration of these in any parts of the sky. On the other hand, we do know that the Milky Way owes its appearance to myriads of faint telescopic stars, which must, on the whole, be more distant because they are so faint. Thus, while the near-by stars seem to be uniformly distributed in all directions, there is an intense concentration for the more distant stars, along that bright belt which is seen in the heavens to encircle our position in space.

Thus we are led to the truth that the boundary of our stellar universe extends to greater distances wherever the Milky Way lies than in all the other directions. And it has now become clear that most of the stars exist there, in a very extended flat ring of

comparatively small thickness, surrounding us, going to enormous distances, while in other directions the region occupied by stars is much more restricted as to distance, and exhibits hardly any very faint stars.

In fact, it has been truly said that, if you could blot out all the stars seen in a 12-inch telescope, the fainter stars which could be seen with a larger telescope would be found to lie almost entirely in the Milky Way. Already we begin to foresee what is true—that this streak of faint light in the sky, to which we used to give but little attention, will prove to be a principal factor in the architecture of the heavens.

Although not brilliant in its northern parts, the Milky Way in its southern half contains the brightest and the most arresting patches of the starlit clouds of glory, with the contrasts of jet-black rifts and blank spots, separating, for example, the bright cloud of Sagittarius the Archer from that of Ophiuchus, or like the "coal-sack" of the Southern Cross in the middle of a brilliant patch. We can well be lost in admiration at the sight. The wonders of these starlit clouds of glory are best exhibited by the photographs which were made by Barnard at the Lick Observatory in California. They came as a revelation to the present writer at the time. It was during a memorable night spent with the great 36-inch refractor there in 1894. Barnard had then begun to take these photographs with an ordinary portrait lens, the camera being strapped to an equatorial telescope, for following the stars by clockwork, while Barnard himself, during hours of close attention with the telescope, was able to correct

any irregularities of the motion. He produced numbers of the most detailed and beautiful photographs in different parts of the Milky Way, solely by his laborious patience in observation.

DISTANCES OF THE STARS.—Immense as is the number of the stars, their distances from us are still more appalling. The human mind cannot conceive them, though expressed in figures derived from accurate measurement. The nearest star to us is Alpha of the Centaur, near the Southern Cross. Its distance is, in fact, twenty-six million million miles away. And astronomers are dealing with stars estimated to be tens of thousands of times more distant, while those objects about which we can form no estimate must be immeasurably farther away. We look upon the sun as being inconceivably distant, though it is only 93,000,000 miles away. Yet its distance is almost as nothing compared with the other stars.

The stars are so prodigiously remote that their measurement has always been considered to be the most difficult of all astronomical observations of precision. It is also, in the present condition of our science, quite the most desirable.

A surveyor wishing to get the distance to an inaccessible peak, measures a base-line, perhaps a mile long, on the ground, and, using his theodolite, he measures the direction of the peak from each end of the base-line. He is then able to calculate the distance of the peak.

So long as the peak is less than, perhaps, a hundred times the length of the base-line he can thus get the

peak's distance with fair accuracy. The farther away the peak is, the more difficult it becomes to be very accurate.

The astronomer who attempts to measure the distance of a star follows precisely the same general plan as the surveyor, although the distance of the star is appalling. He makes use of the very longest base-line available, from the two ends of which it is possible for him to make observations on the star's apparent direction. Such a base-line is given by two positions of the earth, in its annual journey round the sun, at an interval of six months. This base-line has the enormous length of 186,000,000 miles. If circumstances enable him to use only a part of it, his base-line still remains very enormous, though very small indeed compared with the distance he wants to measure.

In this manner three astronomers—Struve, Bessel, and Henderson—independently, and at about the same date (1832-1840), secured observations of three separate stars—Vega, 61 of the Swan, and Alpha of the Centaur—which, for the first time in the world's history, showed an apparent change of place of any star, due to the earth's changing place in its revolution round the sun.

It was Henderson, the Edinburgh astronomer, when observing the place of Alpha of the Centaur from the Cape of Good Hope in 1832-1833, who had the good fortune to select for his study that star which is still recognized as being the nearest of all stars in the universe. Later observers have bettered the observations,

and we know with considerable accuracy that this nearest star is twenty-six billion (26,000,000,000,000) miles distant, or 280,000 times farther away than the sun. If the sun were at that distance we should see it with its brightness reduced in the ratio of 78,400,000,000 to 1. It would then shine only as a star of the third or fourth magnitude, like the smallest of the seven stars in the Plough constellation. It is a surprise thus to find that our brilliant great sun is only a common star, made to look so large and bright only by its nearness.

Such distances are beyond the power of our minds to conceive, and we have to seek some more convenient unit than a mile, or even than the sun's distance. Light travels over the prodigious length of 186,000 miles in a second of time. Anything that happens on the sun is not seen by us for eight minutes. In spite of its enormous speed, light takes all that time to travel from the sun to the earth. It will now become even more clear that the distance of the nearest fixed star is inconceivable when we know that light takes over four years to reach us from Alpha of the Centaur. This star is invisible from England, and the nearest star visible to us is Sirius, the king of stars, and light takes about nine years to reach us from him. This unit, the "light-year" (5,880,000,000,000 miles), is a convenient unit for comparing star distances. The length of a light-year is also 63,290 times the sun's distance from the earth.

The surveyor's method for measuring distances, just spoken of, is the only sure method that can be applied to the stars. A few hundred have thus been measured

with a degree of accuracy concerning which we can say no more than that it is better than nothing.

Working upon these data, attempts have been made with some success to detect empirical relations between the star's distance, its magnitude, and its temperature as judged by spectrum tests (to be referred to presently, see pp. 46, 47). In this way the presumed distances of thousands of stars have been catalogued. Other indirect methods, founded upon fairly sound arguments, have been cordially welcomed in spite of their possible inaccuracies, because the want for this information is so exacting and so urgent.

By one of these methods Sir Frank Dyson, the Astronomer Royal, has found that the nearest stars are not concentrated in the Milky Way, but are fairly evenly distributed in all directions, and occupy a space like a flattened sphere, probably lying within that ring of space which is occupied by the stars of the Milky Way.

The Architecture of the Firmament.—The result of all the studies on these and similar lines by astronomers of to-day has been the pretty general acceptance of a working hypothesis. This is: That the stars in this stellar system, of which our sun is a member, are limited both in numbers and in extent; limited to a few thousands of millions; limited in extent within the boundaries of two distinct regions in space, the far-stretching, flat, ring-shaped galaxy, containing stars of the Milky Way, and the nearly globular space within that ring with our solar system situated near the middle of it.

Our firmament on this view is an island universe in realms of space which probably contain numerous other island universes of the same order of magnitude as our own.

The conclusion arrived at as to the architecture of our own firmament is itself sufficiently startling. There are thousands of people in northern latitudes who rejoice in the glory of a starry night who have never inquired about, perhaps never noticed, that faint white streak, the Milky Way. And now we are led to believe that the Galaxy, or Milky Way, is the fundamental basis of the architecture of the heavens. So it is with many who live in northern climes. Those, however, who travel to more southern regions of the globe form a different impression of the Milky Way, for they behold all the brilliant spectacle of the star-clouds of glory which constitute the southern portions of the Galaxy. Then they can be more ready to accept our Milky Way as the foundation upon which the firmament is built.

CHAPTER V

THE SPECTRUM OF A STAR

A RAINBOW is one of the most beautiful forms in which Nature (the name by which philosophers often allude to the Creator) presents an illustration of the poet's words:

> " 'Beauty is truth, truth beauty,' that is all
> Ye know on earth, and all ye need to know."

And the truth that we get from its beauty is this: the bow, with its centre in the opposite direction from the sun, and with all the spectrum colours—red, orange, yellow, green, blue, indigo, and violet, in that order—appears where rain is falling, while the sun is shining behind us. But the colours are not in the rain. The white light of the sun is sending its rays on to the raindrops. And its white light, when passing through the drop, is decomposed into all of these, its constituent colours.

Nature shows the same beauty, to illustrate a like truth, when a lamp falls on a surface of mother-of-pearl. That surface can be seen through a microscope to be covered with closely parallel striations, like scratched lines on its surface. The reflection of a lamp from that surface shows all the colours of the rainbow in order as before. The colours are not in the mother-of pearl, but in the compound white light of the lamp. In fact, if you take an impression of the mother-of-

pearl in black sealing-wax, it also shows the same rainbow, or spectrum colours.

If a wedge of glass, large enough to cover the whole of a telescope's object-glass, be put in front of that glass, it bends the straight course of light from a star into a new direction, towards the thick edge of the wedge. And, to see the star, the telescope has to be pointed, it may be as much as thirty degrees away from the star. The image of the star in the focus of the telescope can then be examined with the eyepiece.

And this image is found to look no longer like a point of light, but like a streak of all the colours of the rainbow from red to violet. In fact, the star-image has been drawn out by the wedge into a linear "*spectrum*." The truth is that the different colours, of which the star's white light is made up, are all deflected, but each to a different extent—the red perhaps thirty, and the violet thirty and a half degrees.

Thus might the coloured spectrum of a star be examined. And we should find the continuous coloured spectrum broken at intervals, indicating certain colours in which the star's white light is deficient when that light reaches us from the star. The truth is that the vapours in the atmosphere of the star itself absorb certain colours of the star's white light. These missing colours in the light of each star form the chief point of interest when we examine a star's spectrum. These missing colours do, in fact, tell us what materials exist in the star's atmosphere. Iron, hydrogen, calcium, and any other chemical substances,

when hot enough to be in the form of vapour, do absorb certain definite colours from white light that passes through the vapour, each material absorbing its own special colours. Some of them—iron, for example—produce thousands of breaks in the continuous spectrum of colours when examined with powerful optical instruments.

These breaks in the spectrum cannot be very well seen so long as the spectrum in the telescope's focus is only a linear streak variously coloured. An excellent plan for improving them is to use, as a special eye-piece, a lens not having a spherical, but a suitably chosen cylindrical surface. The spectrum then is perfect, and looks like a broad ribbon, red and violet at the ends, and with the other colours in proper order between. Colours that are missing in the light of the star are thus clearly indicated by lines across the coloured ribbon. The position, on the continuous coloured spectrum of a star's light, of each dark line can be measured, and compared with lines found in the spectrum of iron, hydrogen, calcium, etc., during our work with a spectroscope in the laboratory.

* * * * *

The above ingenious device for showing the spectrum of a star, consisting of a wedge in front of a telescope's "object-glass," and a cylindrical lens in its "eyepiece," is one of the forms of "*spectroscope*" used by Father Secchi, at the Collegio Romano in Rome, when the art of spectroscopically detecting the presence of any chemical substance had just been discovered. That was in the sixties of last century, when

Secchi used it for cataloguing the various peculiarities in the spectra of a great number of different stars.

The same results can be attained by other instrumental equipments. Very commonly the prism which disperses, or separates out, the colours of which white light is made can be placed at the eye-end of the telescope. A complete independent spectroscope such as chemists use in their laboratories can thus be attached to the eye-end of a telescope.

Other astronomers imitate the action of mother-of-pearl by scratching upon a metal surface fine lines, thousands to each inch. This ruled "*grating*," when used as a reflector of the star's light, separates the colours into a spectrum.

For the most accurate work astronomers now employ photographic plates to produce what they call "spectrograms" of the different stars. The position of dark lines on these spectrograms can be measured at leisure with extreme precision.

*   *   *   *   *

SPECTRUM ANALYSIS.—In the chemist's laboratory discoveries are made with a spectroscope; and then we make use of the same instrument directed to the stars. The light coming from a white-hot poker, or the carbon of an electric arc-lamp, or any other solid or liquid source of light, shows a spectrum continuous in brightness from the red end, through the orange, yellow, green, blue, and indigo colours to the violet end.

If, however, the source of light be so hot as to be neither solid nor liquid, but vaporized—as when

sodium or common salt is put into a colourless flame of spirit of wine, or as when an electric spark passes from one iron wire to another—the spectrum is no longer continuous. Certain colours only are then sent out from the vibrating atoms of the vaporized material. Thus, with the simplest kind of apparatus, sodium is represented by a bright yellow line. With a refined instrument the presence of iron in a source of light is assured by the glowing of thousands of bright lines in well-measured positions on the spectrogram. So can the lines of all chemical elements be measured, if used instead of sodium or iron.

If, however, we use the low-temperature sodium vapour in conjunction with the high temperature of carbon in an electric arc-lamp, we can make an interesting experiment in the laboratory. And this experiment throws a flood of light on the meaning of what the spectroscope exhibits when pointed to the sun or to any other star.

Experiment.—The spectrum that we see, when looking through a spectroscope at the pure white and hot arc-light, is a ribbon of continuous colour from red to violet. This is the continuous spectrum that is shown by any very hot solid or liquid material, or even by a gas so much compressed as to bring its atoms very close together. If now the flame, containing the sodium vapour at a much lower temperature than the arc-lamp, be interposed in the path of white light from the arc-lamp, a dark line is seen to cross the ribbon spectrum at the yellow colour. The position of this line on the spectrum can be marked by a

pointer. Now remove the arc-lamp. The continuous spectrum disappears and a bright yellow line is seen, exactly where the pointer is.

A refined spectroscope shows many lines besides the very bright yellow one. In this way every chemical substance has been examined in our laboratories, to measure the spectrum lines that belong to each chemical substance.

The astronomer observes the exact place on the spectrum of dark lines, in the light coming from the sun, or any star. The continuous spectrum in that light tells us that what we may call the *body* of the sun or star is a very hot solid or liquid substance, or else gaseous under enormous compression. The dark lines across the continuous spectrum tell us of what materials the sun's or star's cooler atmosphere is composed.

Thus have we learned that, in the sun's atmosphere, which is a star in the same region of space as our earth, there exist fully a half of the number of chemical elements that are known on our earth. Some of the other stars tell the same tale, while in the atmosphere of many other stars hydrogen seems to be the chief component. In others we discover a predominance of compound molecules of titanium, carbon, or zirconium.

* * * * *

Temperature.—The spectrum of iron shows thousands of lines that are reproduced in the spectrum of the sun. Laboratory experiments have shown the spectrum lines of a substance to change their relative

intensity with a change of temperature. Thus astronomers are beginning to know something about the temperature of a star's atmosphere. The temperature of the "body" of a star, the part which creates the continuous spectrum, is indicated by comparing the brightness of two parts—*e.g.*, red and green—of the star's light. The rules for getting the temperature from this comparison have been sought in our laboratories with some success.

RADIAL VELOCITY.—But perhaps the most surprising and fruitful of all spectrum discoveries remains to be told. If we find all the spectrum lines of some star to be slightly shifted in place, either towards the blue or towards the red end of the spectrum, then we know that the star is moving towards or from us. A shift towards *blue* means *approach* to, and towards the *red* means *recession* from us. And if we measure the amount of this shift, we know the speed, in miles per second, at which the approach or recession is being executed.

Thus we learn, by this truly marvellous power of the spectroscope, that our old friend Vega in the Lyre is approaching us at the rate of nine miles a second, while Capella, at the other side of the Pole Star, is receding from us at nineteen miles a second, and Rigel, the brightest star in Orion, at fourteen miles a second. This power of measuring "radial velocities" —*i.e.*, movements in our line of sight to or from us— is in complete agreement with what we know from theory about the manner in which light is transmitted through space (see also pp. 67-69).

CHAPTER VI

DIFFERENT TYPES OF STAR SPECTRUM

It has been found that, while there are great varieties in the spectra of stars, these can, for the majority of stars, be divided into a small number of classes, distinguished by the materials most prominent in their atmospheres, as exhibited by the dark lines in their spectra.

Sirius and Vega and other very white stars exhibit more hydrogen than anything else in their spectra. Capella, like the sun, exhibits chiefly metallic lines, with calcium very marked. Betelgeuse in Orion's shoulder has some resemblance to the latter, but its spectrum is specially marked by dark bands, due to titanium oxide.

The attempts that have been made to estimate the temperature of these stars, at the surface which gives a continuous spectrum, make Sirius and Vega the hottest, perhaps 10,000° C. The sun and Capella would be about 6,000°. We cannot produce such heat artificially. Betelgeuse would be about 3,000°, a temperature so low that we can get it in our laboratories. These three types of spectra are called, by the Harvard College Observatory, Classes A, G, and M—A for Sirius, G for Capella, and M for Betelgeuse.

Stars like Rigel, found chiefly in the constellations

Orion and Carina, show helium added to the hydrogen of Class A, and are called B stars. Some stars can be found between the standard types A and G. They are called F stars; also some between G and M, and they are K stars.

Thus we have a continuous series of spectra:

$$\underbrace{\text{Helium}}_{\text{B}} \quad \underbrace{\text{Hydrogen}}_{\text{A}} \quad \text{F} \quad \underbrace{\text{Calcium}}_{\text{G}} \quad \text{K} \quad \underbrace{\text{Titanium Oxide}}_{\text{M}}$$

There are several other types of spectra. Their alphabetical names, as given by Harvard, are P, O, R, N, and S. These, however, rather militate against the most commonly accepted theory about spectral classes called the Lockyer-Russell evolution theory; and they have to be left out in any general statement of the theory.

The arguments in support of the theory have been so seriously discredited of late years, sometimes by the most determined supporters of the theory, that, in this noncontroversial book, it will be well merely to state the facts and the theory. And even so much is done only because at the present period of our century this evolution theory is being very generally accepted by a majority of astronomers as a working hypothesis.

The most important fact which has been reached is that the temperature of the star's *body* (*i.e.*, the source of the continuous spectrum) rises regularly with each spectral class from M to B. Very possibly, the atmospheric layer wherein absorption of heat and light takes place may also follow the same law. This

absorption is the cause of the dark spectrum lines indicating different materials—helium, hydrogen, calcium and metals generally, titanium oxide.

The next fact is the discovery by Campbell, of the Lick Observatory. All stars have some movement, and the spectroscope enables us to measure the radial velocity of each star. Campbell finds that the average velocity of the M stars, whether giants or dwarfs, is the greatest, over 11 miles a second, the A stars 8, and that of the B stars is the least, about 5 miles a second.

Another fact is that stars of certain spectral types are to be found chiefly in certain particular regions of space. Thus the B stars are mostly in the constellations Orion and Carina. The A stars are, most of them, in the Milky Way. Moreover, these are on the average at 2¼ times the distance of G stars. And about some other localizations of the spectrum classes there is no doubt whatever. Kapteyn estimated the average distance of B stars to be 29 million times the distance of the sun, of A stars 20 million, of F, G, and K stars 9 million, and of M stars 18 million times the distance from sun to earth.

The masses of the stars also seem to diminish regularly in the order of the spectral classes, from B to M.

The Evolution-Hypothesis. — The Lockyer-Russell theory says that a star begins life as a cold nebula. It gets hotter and hotter as time goes on. [The source of the energy of stellar temperature is still a matter of dispute.] While getting hotter it contracts in size

under its own gravitation. It first becomes luminous as a red *giant* M star, the diameter being far greater than that of the sun, and more of the dimensions of the planetary orbits. The temperature rises, and the size contracts until it has a density comparable to the sun. At this stage, if the star be of great mass, it is a B star. Those of less and less mass reach that density sooner, in the stage of Class A, F, G, or even K. Then the star begins to get colder and colder, and it passes through the spectrum classes in reverse order; returning to each class when its temperature has fallen to the condition belonging to that class. Finally it is so cold as to become invisible.

It follows that a very massive star goes through the spectrum-changes in the following order.

$$\underbrace{\text{M, K, G, F, A,}}_{\text{giants}}\ \text{B,}\ \underbrace{\text{A, F, G, K, M.}}_{\text{dwarfs}}$$

*   *   *   *   *

When we know the distances of a good many stars, and their brightness as seen by us at those distances, it is easy to compare their *absolute brightness,* such as they *would* have *if* they were all at the same distance.

Hertzsprung did this. He found that for certain classes of stars, notably those of Class K, all the stars whose distances had been measured were in themselves either very large indeed or very small.

This is what must happen on the Lockyer-Russell hypothesis of evolution, and it was this fact that started H. N. Russell on the giant and dwarf theory.

The giant and dwarf theory has been developed in many ways since it was first propounded. But it ought to be noted how the great Dutch astronomers, van Rhijn, and also Hertzsprung, the discoverer of giants and dwarfs, demonstrate that there are in all probability stars of each class, intermediate in absolute brightness between the giants and dwarfs.

It should also be noted that Campbell, of the Lick Observatory, who discovered the decrease in star velocities from M to B as giants, and their subsequent increase in velocity from B to M as dwarfs, cannot reconcile this with the present hypothesis.

Nor must the forcible remark of Perrine, of the Mt. Wilson Observatory, be neglected: "The physical condition of a star is governed more by its 'locality' than by the age of its evolution."

In the present state of our knowledge, or of our ignorance, in this year of grace 1927, the true astronomer accepts all such theories not as truths of science, but as *working hypotheses* to guide us to new lines of research.

CHAPTER VII

PROPER MOTIONS OF STARS

THE first idea we ever have of the stars is that they are just points of light absolutely fixed in the sky, unchanging, perpetual signals, guides, and helps; placed there at the Creation to remain as they are till the Day of Judgment.

Already we have learnt that they are great big hot things like the sun, made of the same stuff as we find on the earth. Next, we come to learn that they are all in movement. The spectroscope tells us of their motion in our line of sight, what is called their "radial velocity." But long before that was discovered, their minute cross motions among one another had shattered the idea of immobility. People had been accustomed to call them *fixed* stars, to distinguish them from the planets or *wandering* stars. Now we know, by comparing old with modern observations of the positions of stars, that they are all in motion. These motions look to us very small because the stars are so very far away. They are most easy to discover among some of the nearest stars.

Halley, the illustrious Astronomer Royal of Newton's time, was the first to suspect this movement called "proper motion," among the other stars, of Arcturus, Sirius, and Aldebaran, in the year 1718. Arcturus is the bright, lonely star, to which the

Bear's tail, or the handle of the Plough, points (see Fig. 4, p. 10). Since the days when the old Greek astronomer, Hipparchus, measured the star positions, Arcturus has moved, among other stars in its constellation Boötes, over a distance actually amounting to two and a half times the apparent diameter of the moon. In the same time Sirius passed over one and a half diameters. But the wonder does not cease with that discovery. For the distance of Arcturus has been approximately found by observation; and this enables us to convert its *annual proper motion* of over two seconds of arc into a *cross motion* of so many miles per second. In this way it appears that Arcturus is travelling at the prodigious speed of 288 miles a second. Therefore, since Hipparchus measured its position, it must have moved over a distance of something like eighteen billion (18,000,000,000,000) miles; nearly as far as Alpha of the Centaur is from our solar system.

The field open to us for exploring the movement of stars is not now confined to this cross motion, or proper motion, but has been marvellously increased since we learned how, with the help of a spectroscope, to measure the speed of a star's motion, towards or from us, by a shift of the spectrum lines.

The greatest proper motion of any star, now known, is that of Barnard's star, called after the discoverer. This star passes over a space equal to the moon's diameter in the short time of only about 180 years.

Few bright stars have proper motions compar-

able with that of Arcturus or Sirius. Alpha of the Centaur and Vega, however, move very rapidly. The stars of smallest mass seem generally to have the greatest velocities.

We have now got catalogues of the proper motions of thousands of stars. It is interesting, if somewhat laborious, to mark them on a star-chart. Draw a pencil-line on the chart, from each star in the catalogue, with an arrow head to show the direction of its proper motion. Then make the length of this line from the star equal to the star's proper motion, on any scale we may have chosen, say one inch to represent an annual proper motion of one second of arc.

When this has been done, the picture presented by the little lines of proper motion takes a new meaning. The direction of the lines that have been drawn does not appear to be altogether fortuitous. There are signs, here and there, of groups of stars all with a common motion, both in direction and amount; small streams of stars. After looking at such a picture, the universe of stars acquires for us an entirely new character. It is no longer a stationary structure. It gives to us the notion of a flowing universe of interacting suns, some single, others together, whirling through space, over prescribed orbits for us to discover, over recognizable tracks, all guided and governed, in all probability, by the same forces of gravitation, cohesion, elasticity, chemical action, heat, and electricity, whose actions we upon this little world can study in our homes. Such a surprising and invigorating transformation and change of outlook,

from a dry catalogue into a living picture, stirs a fine spirit of speculation in the heart of everyone who cares for the stars.

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It was by drawing for himself such a picture of stellar proper motions that R. A. Proctor found, in those stars of *Ursa Major,* which we call the Plough, one of the best examples of a group of stars all having the same proper motion. Five out of the seven bright stars that give an outline to the Plough (besides the less bright *Alcor,* close to *Mizar,* the middle star of the plough handle), were seen, on his chart, to be all travelling in nearly the same direction, and with the same velocity. And the slight differences almost disappear when we take account of perspective. Later, when the spectroscope was used for measuring radial velocities, towards or from us, these same stars were all found to be approaching us, and at not very different speeds.

A still more wonderful discovery was afterwards made about this *Ursa Major* star-stream. If we know the distance of a star from us, it is easy for a computer to find its exact motion in space from the observed proper motion and radial velocity. Unfortunately there are not many stars whose distance can be measured with sufficient accuracy for this purpose. One of these, however, is Sirius, the brightest star in the sky; and the discovery has been made that its motion in space is from the same point of the sky, the perspective "radiant point" of the group of six

Plough stars. Altogether, six stars in different constellations are suspected to be additional members of the *Ursa Major* star-stream, all going the same way as that stream, and at about the same speed. That Sirius, south of the heavenly equator, far distant from the stars in the northern Plough, should belong to the same group opens up a completely new conception of our own situation in the stellar universe.

* * * * *

THE PLEIADES.—Let us make another call upon a family of old friends among the stars, to hear about their travels. On the west side of Orion is the somewhat ruddy Aldebaran, Alpha of the Bull constellation. It is one of the lighthouses on the ecliptic, the trade route of the planets. That route passes between Aldebaran and the lovely little cluster of stars still farther west, called the Pleiades. These Pleiades, a bunch of six to most people, and of eleven to really good eyes, are a very wonderful group in many ways. They are all helium stars, and they are, each of them, enveloped in nebulous streaky light of great extent. There used to be seven stars, not six. One seems to have been lost during historical times. When the proper motions of the six bright stars are looked at on the chart they all point in the same direction. The telescope reveals two hundred and forty-six stars in the cluster between the third and fifteenth magnitudes, all travelling in much the same direction at the rate of about five and a half seconds per century. We may now pass from this beautiful

little nosegay of buds to an equally lovely double spray of starry petals.

THE HYADES.—In the same part of the sky there is a beautiful little string of stars, V-shaped, with Aldebaran at one end of the V, called the Hyades. Our pleasure in noticing them is very much increased when we are aware that about forty of them, mostly telescopic, make up the most wonderful family of migrant stars as yet discovered, all streaming at the same pace in one direction. So accurately are they doing this that the effects of perspective are quite marked when we plot them, with their observed proper motions, on a large scale star-chart. The little lines on the chart are seen to point with wonderful exactness to the radiant point, towards which they are all flying, the lengths of lines nearest to that point being rather shorter than those farther from it. This is all quite in accord with the laws of perspective. The radial velocities as found by the spectroscope confirm this truth.

These stars, at their present distances from us, are ranked as of the third to the seventh magnitudes and cover fifteen degrees. In the distant future, after sixty-five million years shall have elapsed, Professor Boss calculates that this cluster will be condensed so as to cover not more than one-third of a degree, with the stars reduced to the ninth to twelfth magnitude.

* * * * *

SOLAR MOTION.—Soon after a small number of proper motions had been measured, in different parts

of the sky, a general tendency was evident for their apparent courses to radiate or diverge from a spot in the region of Vega, Alpha of the Lyre constellation, or from some point in the neighbouring constellation *Hercules*. [Naturally, the stars whose proper motions show this effect to the greatest extent are the stars which lie in the region about ninety degrees from Vega.] The fact is now quite well established. Does this mean a general tendency of all stars to move in one direction—away from Vega? Or does it mean that our solar system is moving towards Vega? The effect would be exactly the same on either supposition, and we cannot ever detect absolute motion, only relative. But the simple motion of only one star, the sun, is certainly the clearest expression of the observed facts.

The power of the spectroscope in telling us the speed with which a star is approaching or receding from us has also been applied to get the direction and amount of the solar motion. The result has always been to show that the stars near Vega are all approaching us, while those at the opposite part of the sky are receding. This discovery confirms beautifully and perfectly the general result already derived from proper motions. This is doubly satisfactory, because the stars that are most effective in showing this solar motion by radial velocities are those near the line going to Vega; while the stars most effective with proper motion are on the circle of stars round us, which are ninety degrees away from Vega. In fact, it follows that two totally different sets of stars give

very nearly the same direction for the solar motion. The spectroscopic method, however, has this advantage. It tells us the actual velocity of the sun's motion among the stars, towards Vega. It is about fourteen miles a second—that is to say, a little quicker than the motion of our earth round the sun.

* * * * *

THE TWO STAR DRIFTS.—After the question of the solar motion had been worked out so well, by taking the *mean* proper motions or the *mean* radial velocities of many stars in each part of the sky, the question arose as to the *individual* motions that go to constitute the mean. Are these individual motions of the stars entirely at random? Or, do the stars themselves drift to any extent in swarms independent of solar motion?

The latter supposition seemed likely from the fact that when we take several particular classes of stars, we do not get quite the same result for the solar motion. Notably, the stars lying near to the line of the sun's motion indicate by their radial velocities a solar motion to a direction southward of that given by proper motions of those stars lying in the plane at right-angles to the solar motion. This indicates that the stars in line with Vega have a small mean motion of their own in a northerly direction relatively to the other stars.

Eventually, the theory of drifting in swarms was demonstrated, and in an unexpected form, early in the present century, by that brilliant successor to the

methods of Sir William Herschel, Professor Kapteyn of Leyden, Holland.

He found that the mean proper motions of stars in different parts of the sky are not accounted for by a solar motion alone. They are, however, extremely well accounted for by *a solar motion in one direction towards Vega, combined with a general drifting of the stars, one lot of them in a direction inclined at forty-six degrees to the solar motion, and the others in exactly the opposite direction.*

This two-drift theory of stellar motions is one of the grandest generalizations ever made in sidereal astronomy. It has been derived, however, from the proper motions of stars near enough to us for exact measurement. It need not apply to very distant stars or to the whole stellar universe. It may be local to our part of it.

Be that as it may, we can rejoice at the splendid start which has now been made in the exploration of the necessarily complex system of local movements among stars, of individuals, small groups, and enormous crowds, in the near regions of our vast stellar universe.

CHAPTER VIII

DOUBLE STARS

AMONG the many new stellar discoveries made by the invention of the telescope, from the year 1610 onwards, it was found that stars which look single to the naked eye are often in reality double stars, a very close pair. The first discovery of this kind was Mizar in the tail of the Great Bear, by Riccioli about 1650. Soon afterwards a star in the *Ram* constellation, Castor in the *Twins,* and Gamma of the *Virgin,* were added. Huyghens, in 1656, found Theta of Orion, in the middle of the great nebula or luminous cloud, to consist of three distinct stars all very close together. Many more were added in the eighteenth century; so many, in fact, that the opinion arose that these double stars are not merely in the same direction, and still separated by enormous distances in the line of sight, but that they are really close together in space and physically connected.

In the nineteenth century the spectroscope provided us with a new power, to be described presently, of detecting double stars, although they look single even in the most powerful telescope.

And to-day, in the twentieth century, the opinion prevails that at least one out of every four or five stars in the whole firmament is double.

Some double stars can be seen even without the aid

of a telescope. Mizar is the Arabic name for the middle star in the tail of the *Great Bear*. A companion star, called Alcor, can be seen close to it with the naked eye. In a telescope they are too far apart to be classed as double star. But Mizar itself is a true double star, the first that was ever discovered, as already stated.

Beside our friend Vega, overhead of a summer night, are two little stars forming with it a regular triangle. One of these is *Epsilon* of the Lyre. When attention is fixed upon it, no telescope is required to see that it is double. Even if not seen separate by some eyes, they look like an elongated star, owing to the double character. An opera glass will make this quite clear. The wonderful part of the story is that a moderate telescope shows each of these two little stars of which *Epsilon Lyræ* is composed to be itself double.

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COLOURED DOUBLE STARS.—A study of double stars is a favourite starting-point for the young astronomer. And his interest in them is increased by the beautiful contrasts of colour often displayed by such a pair of gems. Moreover, the close double stars form one of the finest tests of the performance of a telescope; and in this way amateurs get a new zest to their hobby in comparing the performances of rival telescopes.

To give a single example of striking colours in double stars a telescope may be directed to that beautiful object, Gamma of Andromeda. It is easy to find towards the close of the year, when the great square of

Pegasus is conspicuous in the southern sky (see Fig. 2, p. 9). Three bright stars run in a straight line from the north-east corner of the square to Persius. These three stars lie beneath the west of Cassiopeia. They are the three brightest stars in the constellation *Andromeda,* and the third one is *Gamma*. A moderate telescope shows it to be double, a large orange star and a smaller emerald-green one. A more powerful glass resolves this last one into two, one blue, the other yellow. This is one example of many multiple-coloured suns that give delight to all who start upon the exciting sport of hunting up double, and multiple, and coloured stars, with the help of a telescope, a guide-book such as Webb's, and, perhaps best of all, an experienced friend.

When we have the good fortune to see through a telescope these sparkling gems, the imagination is apt to run riot about any inhabitants of any planets that may belong to these suns. There the supposed human beings would live in a magical world of colour, where the red sun sets, and a blue or emerald sun remains shining upon the world, as when we see a landscape through blue, orange, or rose-coloured glasses.

During the time that a blue sun is eclipsing a red one, what weird alternations of colour may transform the aspect of a country scene! On such a planet there may be long periods with no darkness of night. For twelve hours a sun may have flooded the outer world and the interior of the home with rose-coloured tints, and after it sets there may follow twelve hours of green light from another pair of suns, one blue, the

other yellow. Then a moon may pass and eclipse one or other of these, leaving people in a world of blue or yellow light. That moon itself may be lighted by the two or three suns, and may show varying tints of combined colours over different parts of its surface. Then, again, how inconvenient must it be to have to do with both "red solar time" and "blue solar time" at the same hour! And yet, if there be people to see these things, they probably accept them as being what ought to be expected, rather than as a heavenly wonder.

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SOLAR SYSTEMS AMONG THE STARS.—Sir Isaac Newton proved the law of gravitation to be universal in the solar system. Its action is manifested not only by the weight of things we handle, attracted towards the centre of the earth, but specially by the revolution of bodies round each other, as the planets revolve round the sun, or the moon round the earth, in the solar system.

It was reserved for Sir William Herschel, in 1803 and 1804, after thirty years of painstaking measurements, to extend the range of Newton's law, to state positively the splendid result of a comparison between his earlier observations of double stars and those made by him twenty years later. He found unmistakable proof that in many cases the pair are revolving round their common centre of gravity. This happens *under the same law of gravitation as that which holds the solar system together.* He gave even rough approximations to the periods of revolution. In the arch of

bright stars framing the constellation of Orion (Fig. 1, p. 5) the twins Castor and Pollux are conspicuous. Castor is the one nearest to Capella. To this star Herschel gave a period of 342 years. The head of the *Lion* constellation (Fig. 3, p. 9) has a string of stars tracing the shape of a reaper's sickle. The brightest of those in the blade of the sickle is *Gamma*. It is a double star, and Herschel gave to it a period of 1,200 years.

In 1830, Savary published the mathematical formula for computing the true orbit of a binary pair of stars, and applied his method to one of Herschel's binaries in the toe of the *Great Bear*. Thus Xi of Ursa Major was the first source of positive evidence that Newton's law extends beyond the solar system to the stars. It was a glorious achievement.

Herschel was followed in this study by the painstaking William Struve. He published a catalogue of about 3,000 double stars from an examination of no fewer than 120,000 stars. All double stars are not binary stars like those discovered by Herschel. That term is used only for a pair revolving round each other under the action of gravity, forming, in fact, solar systems among the stars. There is no evidence, however, for or against the existence of any family of small dark *planets*, like ours, illuminated by, and revolving round, these distant suns. The number of known binary stars is to-day very great.

Castor and Pollux in the northern skies have their counterpart to our antipodean friends in Alpha and Beta of the Centaur, an even more brilliant couple

than the twins, pointing to the Southern Cross. Of these, Alpha resembles Castor in being double, and both stars of which it is composed are very bright. Halley discovered its double character in 1689. Its period is eighty years, and the pair have been followed through three revolutions in their elliptic orbit round each other. They are nearly equal in size. The brighter one resembles our own sun very closely in mass, brightness, and probably in temperature, and seems to be made of the same materials.

It is a wonderful consequence of Newton's law of gravitation that *we are actually able to weigh these binary stars* from a knowledge of their period of revolution, their separation apart, and their distance from us. As a general rule it has been found, in the limited number of cases where the distance has been measured, that most stars in the binary systems are of the same order of mass as the sun. Some may be ten times as massive, exceptional ones even more.

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SPECTROSCOPIC BINARIES.—The discovery of solar systems among the stars, controlled like our solar system by the force of gravitation, has been vastly expanded during the last thirty years. This has followed from the new power given to us by the spectroscope.

That instrument was first applied to the stars in the hope of finding what materials known to us on the earth are also present in different stars. This side of the question has made great progress, but the facts have been somewhat obscured by their interpretation, according to conflicting hypotheses.

The secondary results of applying a spectroscope to the stars is even more wonderful, and is now free from controversy, and tells us, with astronomical precision, *the rate at which any star is approaching us or receding from us*. And the spectroscope actually measures these velocities in miles per second. How can this be done?

Sound is transmitted to our ears by vibrations through the air. Light is transmitted to our eyes by vibrations through the all-pervading ether.

The pitch of a musical note is higher as the air vibrations succeed each other more rapidly. Low notes slower, high notes faster. The colour of a line in the spectrum of a star is farther towards the blue end of the spectrum as the ether vibrations succeed each other more rapidly, red vibrations slower, blue ones faster.

If the source of sound, or of light, is approaching us, the ear or eye catches more vibrations in a second than when it is at rest. So the pitch of a note is raised when approaching, as also it is lowered when receding. So also the colour of a spectrum line is shifted towards the blue end of the spectrum when a star is approaching us, as also towards the red end when receding. For the case of sound we have a good illustration, thus:

If you are standing at a railway station when a whistling locomotive dashes through the station, then, at the moment when it passes you, the pitch of its whistle is lowered, it may be as much as an octave. Take notice of this when you get the chance.

For the case of light, if we point a spectroscope to

the sun, at its centre, its east edge, and its west edge, we see the spectrum lines of the east side shifted to the blue, and of the west side shifted towards the red; because by the sun's rotation on its axis the east side is approaching us, and the west side receding.

The Harvard College Observatory, U.S.A., with very moderate equipment, during the directorship of the late E. C. Pickering, started new and original lines of research, and did supply the world with some discoveries of first-class importance to astronomy. One of the greatest had to do with Mizar in the tail of the *Great Bear,* the first double star known, as already told, also the first double star to be photographed. In 1889, Pickering announced a discovery by his assistant, Miss Leavitt. She found that the dark lines in the spectrum of the brighter of the two stars of which the visual binary, Mizar, is composed, are double at regular intervals of time, and single between times. The double spectrum proves that the light comes from two separate stars, so close together as to look like one, and that one of them alternately is approaching or receding from us while the other is receding or approaching, giving a double shift of lines. In the intervals, when they neither approach nor recede, there is no relative shift of lines. They remain single.

Clearly the two stars are revolving round each other, alternately approaching us. When one star is at its greatest distance from us and the other at the least distance, their movement is all across the line of sight. There is no shift of spectrum lines, and these lines look single.

Finally, it was shown that the two stars of Mizar revolve round each other once in three weeks, that their distance apart is about the same as Mercury's distance from the sun; and lastly, that their combined mass is twenty times that of the sun.

Miss Leavitt's discovery has opened up a new branch of astronomy, and numerous "spectroscopic binaries" are constantly being added to the list.

The very first stars in which the spectrum lines were found to be periodically doubled, after Mizar, were our old friends Capella and her bright neighbour Beta of the same constellation, Auriga the Charioteer. None of these spectroscopic binaries has been seen as a double in the telescope. During the present decade, however, the invention of a new method for testing and measuring very close doubles has been entirely successful in the case of Capella, and every astronomer rejoiced at the confirmation, thus established, of the spectroscopic discovery.

Sometimes one of the two revolving stars of a spectroscopic binary is non-luminous. In such cases the spectrum lines are not doubled, but their periodical alternate shift to red and blue proves the existence of the invisible dark companion attracting the luminous body. Spica in the Virgin (Fig. 4, p. 10) was the first star thus found to have a dark companion.

CHAPTER IX

VARIABLE STARS

We have now discovered that the stars are very far from being merely fixed points of light, which is the impression natural to a first outlook. They are all in motion.

There is one more important feature by which a certain individuality is shown among the stars. Many stars are constantly undergoing changes in brightness, some periodically at regular intervals, others with every conceivable degree of irregularity. The range of brightness may be very small and may take a long time to be accentuated. In other cases their brightness may change, from invisibility in a good telescope, to a rivalry with some of the brightest stars in the heavens, in the course of a day or two.

Irregular Variables, and New Stars or "Novæ."—It becomes less and less possible, with the modern great increase in the number that are discovered, to separate these two classes of variables. A "new star," or *Nova,* burst forth in 1918 in the constellation *The Eagle.* It was one of the brightest of the number, some thirty in all, that have been seen with the naked eye in historic times. Previously, it had been a variable star of the eleventh magnitude. It attained almost the brightness of Sirius in a few days, and then slowly faded away; and now it shines once

more a faint variable star, as before its great outburst. The wild erratic changes in its spectrum were astonishing. This passed from being a continuous spectrum with dark lines, in a few days, to a spectrum of luminous bands due to hydrogen, indicating vortical movement. And these two spectra were often seen together. The dark lines of hydrogen, when compared in position on the spectrum with the bright bands of hydrogen, indicated the presence of two different bodies, with different velocities in the line of sight. The dark lines were shifted towards the blue end of the spectrum to an extent that indicated a velocity of approach towards us at the rate of some 2,000 miles a second compared with the bright bands of hydrogen.

In every one of these features Nova Aquilæ, 1918, went through phases commonly observed in all the *novæ*. No complete theory has as yet accounted for all the facts. The dual character, indicated by the spectra of two bodies, one of which moves rapidly compared with the other, has brought forward an explanation suggested by the luminous shooting stars and fireballs. These fly across the sky through the atmosphere, heated to incandescence by air friction, showing a continuous spectrum, while their trails of glowing gases are stationary in the atmosphere.

This theory of the outburst of a nova, like all of them, is still incomplete, but is perhaps the most likely one to prevail. It pre-supposes a collision between a star and one of the gaseous masses that are called nebulæ. These gaseous clouds frequent the

Milky Way, as do also the new stars. The gaseous friction would certainly heat the star and leave a glowing gaseous trail, just like a fireball. And gaseous nebulæ have been found surrounding new stars.

This is not the place to discuss the merits and defects of imperfect hypotheses. The gas friction theory is mentioned here because it may apply equally to new stars and to the next class of variables.

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IRREGULAR VARIABLES.—The most typical irregular variable is *Eta* of *Carina* in the southern hemisphere. Its history also is the most extraordinary of all. At present a telescope is needed to see it, because, for a great many years, it has not been shining brightly. But, with a telescope it is seen beautifully situated in the middle of a wonderful cloud-spot, or gaseous nebula, which is spread out into a map of strange forms of glowing gas, called the keyhole nebula. Many of the irregular variables are thus seen to be associated with nebula, as are some "new stars." This fact leads us naturally to adopt, temporarily, at least, for want of a better one, the gas friction theory equally applicable to *new stars* and *irregular variables*, both of which brighten up when traversing the nebula.

The history of the most remarkable "irregular variable," Eta Carinæ (formerly known as Eta Argûs), so far as known, is this. In 1677, Halley saw it of magnitude 4; in 1687 it was magnitude 2; in 1751

Lacaille's observation was 2; from 1811 to 1815 it was 4; in 1827, it was of first magnitude. In 1843 it was -1, nearly as bright as Sirius. It fell off till 1870. Since then it has fluctuated about the seventh or eighth magnitude. All this is compatible with the resistance offered to the star's passage through dense and less dense parts of the great Argo nebula. But that is only an hypothesis *pro tem.*

The new star in the southern constellation Pictor, discovered in 1925, is intermediate between a nova and a variable. It was found in old photographs to have a magnitude 12 or 13, from 1889 to 1925. On April 13 in that year its magnitude was 3. It was not discovered until six weeks later. From May 28 to June 9 it brightened from magnitude 2·6 to 0·9. After June 20, in some months, it fell to third magnitude or thereabouts, and then fell off still more in brightness.

Its spectrum, and that of many new stars, resembles the spectrum of Eta of Carina, the great irregular variable star.

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LONG-PERIOD VARIABLES.—There is no department in astronomy towards which amateur societies, like the British Astronomical Association, contribute so much in the way of continuous observation as that of long period variables. This class includes all the variable stars that were first discovered centuries ago, except *Algol*. The first was by Fabricius, in 1516. His variable star is *Omicron* in *Cetus* the whale,

often called *Mira Ceti* (the wonderful). It is generally invisible to the naked eye, but is bright for three months in the year, sometimes rivalling Aldebaran. The variable stars of this class have periods (the interval of time from maximum to maximum) varying in different stars from 80 to 500 or 600 days. All other regular variables have periods not greater than a few days.

It is remarkable that this type of star is more surely detected by its spectrum than by its period. They all belong to the M stars, and their spectra all show some *bright* hydrogen lines, forming a sub-class Md. Every known Md star is a long-period variable, and 85 per cent. of long-period variables have been proved to be Md stars. About 400 of them are known.

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Delta Cephei Variables.—Short period variables, called after the fourth magnitude star Delta of *Cepheus* form a numerous class. This star, at intervals of five days and eight hours, brightens almost to third magnitude. Then it falls off for four days, after which it brightens rather suddenly. There is a large number of these delta cepheids, found mostly in the Milky Way.

Cluster Variables.—There are in certain sections of the sky about eighty small telescopic "*globular clusters*" of minute stars in which large numbers of short-period variables have been found having all the characteristics of Delta Cephei; except that the *period*

is generally only a fraction of a day. This remarkable discovery was first made by Bailey in regard to the globular cluster *Omega* of the *Centaur*. He found, not only more variable stars in that cluster than were already known in all other parts of the heavens, but that all of them had the same period of about half a day.

ALGOL VARIABLES.—*Persius* constellation is the string of stars that passes from Cassopeia to the Pleiades. The two brightest stars are Alpha and Beta, generally about equal in brightness, of magnitude 2. Beta, a little to the right of the string of stars, is called Algol (Arabic for the Demon). It really consists of two stars, one bright, the other dark. They revolve round each other; and every three days or so the bright star of the pair is partially hidden or eclipsed by the dark one (which is about equal to it in size), and its brightness is reduced to one quarter, for about twenty minutes. In about three and a half hours it again reaches the second magnitude, which it retains for two and a half days.

The Algol variables all go through the same kind of changes with incredible punctuality. The hours of minimum brightness can be safely predicted years ahead. There are some, like Beta of the *Lyre*, where the companion is not dark. For this reason, twice in each revolution of the pair, we see only the light of one star instead of both, and so we see two minima in each revolution.

CHAPTER X

THE FRIENDSHIP OF THE STARS

Epilogue.—The author has now concluded a brief account of some of the marvels which are the daily bread of astronomers in their study of the stars. The reader ought now to know how to make a personal acquaintance with many of these objects of his admiration.

An attempt has been made in this book to enable him to take note of, and to understand, the varying characters of different stars, and to transform his mere acquaintanceship, and recognition of them, into a real personal friendship.

Let anyone who has read these pages, and who has identified in the sky many of the stars described, recall everything that he now knows about the individual character of each of the following stars: the splendid Sirius, the steel-blue Vega, the golden Capella, Mizar, Betelgeuse, Mira of Cetus, Algol, Alpha and Omega of the Centaur, Arcturus, Spica, the star groups of Pleiades and Hyades beside Aldebaran. If then he does not feel his heart beat a little quicker, when one of these old friends, or a blazing planet, comes into view, and when he describes its marvels to the companion of his midnight stroll, then it must be confessed that the purpose of these pages can only have

been partially attained. If, on the other hand, the reader can now see more clearly the wonder and the glory of the stars, then it may be hoped that the friendship of the stars may likewise become to him a reality and a pleasure. *Vale.*

BIBLIOGRAPHY

H. R. Gall and A. Inglis: *Easy Guide to the Constellations.* (Gall and Inglis.)

Sir Robert Ball: *Story of the Heavens.* (Cassell.)

Hutchinson's *Splendour of the Heavens.* 2 vols. Edited by Rev. T. E. R. Philips and Dr. W. H. Stevenson. (Hutchinson.)

Professor George Forbes: (1) *The Wonder and the Glory of the Stars* (Benn); (2) *History of Astronomy* (Watts).

Professor Herbert Dingle: *Modern Astrophysics.* (Collins, Sons and Co.)

Miss Agnes Clerke: *Popular History of Astronomy in the Nineteenth Century* (Black.)

For a deeper study, the following books should be read:

Robert Grant: *History of Physical Astronomy* (Baldwin.)

Sir George Airy: *Six Lectures on Astronomy.* (Simpkin and Marshall.)

Sir John Herschel: *Outlines of Astronomy.* (Longmans, Green and Co.)

H. N. Russell, R. S. Dugan, and J. G. Stewart: *Astronomy.* (Ginn and Co., New York.)

Also Norton's Star Maps or Atlas.

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